Infrastructure Investment: The Foundation of Canadian Competitiveness

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August 2008 | Vol. 9 | no. 2

Biographical Notes

James A. Brox is professor of economics at the University of Waterloo. He is the author of over one hundred articles, books, book chapters, monographs and technical reports on various economic issues, usually with a strong policy focus. He has been chair of the economics department at the University of Waterloo (1996-2005), president of the University of Waterloo Faculty Association (1984-86 and 1992-94) and associate dean of arts for computing (1989-1990). He is currently president-elect of the International Banking, Economics, and Finance Association (formerly the North American Economics and Finance Association). He is an honorary life member of the Atlantic Canada Economics Association.

Summary

Large infrastructure projects have been at the heart of Canada's development throughout the nation's history. There are many examples: the Canadian Pacific Railway, the Trans-Canada Pipeline, the Trans-Canada Highway, the St. Lawrence Seaway, Expo '67, the Montreal and Calgary Olympic facilities and, more recently, the Confederation Bridge linking Prince Edward Island to the rest of Canada.

In this study, James Brox examines the so-called "infrastructure gap" and its adverse impact on Canadian manufacturing costs and productivity. Investment in public infrastructure (including highways, port facilities, water treatment and distribution systems, public safety services such as police and fire protection, garbage collection and disposal, sewage treatment and other public utilities) has fallen to just over one-half of its average value in the 1960s, measured as a percentage of GDP, and key facilities are crumbling (as the collapse of the Boulevard de la Concorde overpass and the contamination of the water supply in Walkerton tragically illustrate). The author estimates that an injection of up to $200 billion — $72 billion for new projects and $123 billion for maintenance of existing facilities — will be necessary over the coming years to close the gap. Major infrastructure initiatives recently announced by the federal, Ontario and Quebec governments commit up to $65 billion over the next five to ten years, but it is clear that this financial commitment will need to be sustained (and even increased) over an even longer period of time to close the infrastructure gap fully.

The decline of Canada's infrastructure stock has coincided with a market slowdown in productivity growth of the manufacturing sector, especially in comparison with the United States. Manufacturing productivity levels were almost identical in the two countries in the mid-1990s, but by 2006 the U.S. level was over 20 percent higher. Over the same period, infrastructure investment in Canada declined by 3.5 percent, compared with a 24 percent increase in the United States.

These relationships are not coincidental, but rather reflect the fact that services provided by public infrastructure enter both directly and indirectly into private-sector manufacturing. Directly, they make up a portion of intermediate inputs used in the production process. For example, firms need water, power, transportation facilities, etc. to man-

ufacture and deliver their goods. The existence of infrastructure facilities also allows firms to modify their own investment plans. For example, a newly constructed controlled-access highway could increase a manufacturer's competitiveness by reducing transport costs (with regard to both the number of trucks required and vehicle maintenance costs). Other kinds of infrastructure investment (such as sewer systems) promote economic development and increase private investment. The author reviews the extensive literature on the infrastructure-production relationship.

Using historical Canadian data and a flexible-form production function approach, Brox quantifies the effect of infrastructure investment on the cost structure of Canadian manufacturers, and finds that a sustained 10 percent annual increase in infrastructure investment (which is approximately the amount promised in recent federal and provincial infrastructure initiatives) could reduce manufacturing unit production costs by nearly 5 percent per year — a welcome development in the context of the strong Canadian dollar. A 5 percent improvement in unit production costs is equivalent to a 5 percent increase in productivity. This would help narrow the Canada-U.S. manufacturing productivity gap and enhance the sector's competitive profile.

Brox also finds that public infrastructure tends to substitute for private investment in the short term, allowing companies to allocate resources to other inputs. Over a longer time frame, however, the productivity of private capital is enhanced by infrastructure, which increases the number of profitable investment projects. A second observation, which is not immediately intuitive, is that infrastructure investment encourages manufacturing firms to use labour inputs somewhat more intensively, which translates into more jobs. While the magnitude is small when measured against recent job losses and would not come close to offsetting them, this fact dispels the common (but misplaced) fear that increases in productivity growth cause unemployment.

Public infrastructure has built Canada, and the author concludes that if federal, provincial and municipal governments do not start shoring up our infrastructure deficit now, the future costs may be more than we can bear either physically or financially. Canadian competitiveness and our status as a developed country depend on a modern, efficient, well-maintained public infrastructure stock.

Résumé

Les grands projets d'infrastructure ont été au cœur du développement du Canada tout au long de l'histoire du pays. Les exemples abondent, du chemin de fer Canadien Pacifique au pipeline transcanadien en passant par la route transcanadienne, la Voie maritime du Saint-Laurent, l'Expo 67, les installations olympiques de Montréal et de Calgary ou, plus récemment, le Pont de la Confédération reliant l'Île-du-Prince-Édouard au reste du pays.

Dans cette étude, James Brox examine ce « déficit d'infrastructures » et son incidence nuisible sur les coûts de fabrication et la productivité. L'investissement actuel dans les infrastructures (y compris les routes, les installations portuaires et les systèmes de traitement et de distribution d'eau, les services de sécurité publique comme la police, la prévention des incendies ou la collecte et le traitement des ordures, sans oublier le traitement des eaux usées et autres services publics) s'établit en valeur moyenne à un peu plus de la moitié de ce qu'il était dans les années 1960 par rapport au PIB, alors même que s'effritent certains équipements majeurs (comme l'ont tragiquement illustré l'effondrement du viaduc du boulevard de la Concorde ou la contamination de l'approvisionnement en eau à Walkerton). L'auteur estime à 200 milliards de dollars la somme à injecter pour combler ce déficit, soit 72 milliards en nouveaux projets et 123 milliards pour l'entretien des installations existantes. Les grandes initiatives récemment annoncées par Ottawa, le Québec et l'Ontario engageront jusqu'à 65 milliards sur les 5 à 10 prochaines années, mais il faudra soutenir (et même accroître) cet investissement sur une période beaucoup plus longue pour combler pleinement le déficit existant.

Le déclin de notre stock d'équipements a coïncidé avec un recul de la croissance de la productivité des fabricants, surtout par rapport aux États-Unis. Le niveau de productivité manufacturière des deux pays était en effet presque identique jusqu'au milieu des années 1990, mais en 2006, celui des États-Unis avait surpassé le nôtre de près de 20 p. 100. Durant cette même période, l'investissement dans les infrastructures a reculé de 3,5 p. 100 au Canada alors qu'il augmentait de 24 p. 100 aux États-Unis.

Ces liens comparatifs n'ont rien d'un hasard mais indiquent plutôt que les services fournis par les équipements publics s'intègrent à la fois directement et indirectement au secteur manufacturier. Directement, ils comptent pour une partie des intrants intermédiaires du processus de production, puisque les entreprises ont besoin d'eau, d'électricité ou de réseaux routiers pour fabriquer et livrer leur biens. Les équipements d'infrastructure leur permettent en outre de modifier leurs plans d'investissement. Par exemple, une nouvelle route à accès limité pourra favoriser la compétitivité d'un fabricant en réduisant ses frais de transport (pour ce qui est à la fois du nombre de camions et de leur entretien). D'autres formes d'investissement (dans le traitement des eaux usées, par exemple) favoriseront le développement économique et l'investissement privé.

Pour étayer ce point de vue, l'auteur a analysé une abondante documentation sur le rapport infrastructure-production. Il s'est aussi fondé sur les données historiques canadiennes et une approche flexible de la fonction de production pour quantifier l'effet des investissements d'infrastructure sur la structure de coûts des fabricants canadiens. Sa conclusion : en augmentant de façon soutenue ces investissements de 10 p. 100 par année (ce qui correspond à peu près au coût des initiatives fédérales et provinciales annoncées), on réduirait de près de 5 p. 100 par an le coût unitaire des produits manufacturés. Une réduction bienvenue étant donné la force actuelle du dollar canadien, d'autant plus qu'elle équivaudrait à une hausse de 5 p. 100 de la productivité. Ce qui aiderait à réduire l'écart entre la productivité manufacturière du Canada et des États-Unis tout en renforçant la capacité concurrentielle du secteur.

L'auteur note aussi que les infrastructures publiques tendent à remplacer à court terme les investissements privés, ce qui permet aux entreprises d'affecter des ressources à d'autres intrants. Mais elles renforcent à plus long terme la productivité du capital privé, ce qui permet de multiplier les projets d'investissement lucratifs. Autre effet moins perceptible à brève échéance : les investissements d'infrastructure incitent les entreprises manufacturières à miser plus fortement sur l'apport de main-d'œuvre, ce qui se traduit cette fois par un plus grand nombre d'emplois. Cet effet reste mineur par rapport aux récentes suppressions d'emplois et ne pourrait en compenser la perte, mais il réfuterait les craintes courantes (quoique non fondées) selon lesquelles l'accroissement de la productivité est source de chômage.

Le Canada s'est bâti grâce à ses infrastructures publiques, conclut James Brox, pour qui les gouvernements fédéral, provinciaux et municipaux doivent entreprendre immédiatement de combler notre déficit d'infrastructures au risque d'être incapables d'assumer à plus long terme les coûts matériels et financiers. Or notre compétitivité et notre statut de pays développé reposent sur un capital d'infrastructures modernes, rentables et parfaitement entretenues.

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Introduction

As any student of Canadian history who has read Pierre Berton knows, from Sir John A. Macdonald's "National Dream" to the "Last Spike" driven by Donald Smith, Canada has literally been built on infrastructure. Large infrastructure projects have been at the heart of Canadian development. There are many examples: the Canadian Pacific Railway, the Trans-Canada Pipeline, the Trans-Canada Highway, the St. Lawrence Seaway, Expo 67, the Montreal and Calgary Olympic facilities and, more recently, the Confederation Bridge linking Prince Edward Island to the rest of Canada.

The role of public infrastructure in business productivity is well established. The *Canadian Oxford Dictionary* defines infrastructure as "the basic structural foundations ... roads, bridges, sewers, etc., regarded as a country's economic foundation" (729). However, public infrastructure expenditure has fallen since 1970 to just over one-half of its average 1960-70 value, measured as a percentage of GDP. This is one of the reasons for the productivity slowdown that has occurred since the relatively stronger economic growth of the 1960s and 1970s. The hypothesis that public infrastructure is key to productivity growth was first contemplated by Ratner (1983); it was developed empirically and then delivered widely to both academic and political communities by Aschauer (1988, 1989a, 1989b, 1990, 1991).

This premise has a great deal of intuitive appeal. Public infrastructure capital stock includes highways; other transportation facilities, including docks and ports; water treatment and distribution systems; public safety systems such as police and fire protection; collection and disposal of garbage; sewage treatment; and other public services that provide the necessary environment for private production to occur.

Services provided by public infrastructure enter both directly and indirectly into the private production process and therefore affect the productivity of the private economy. Directly, they make up a portion of the intermediate inputs or services used in the production process. For example, firms need water, power, transportation facilities, etc., to produce. There is also an indirect relationship because private and public capital may well be considered complements in some cases, substitutes in others. For example, a newly constructed controlled-access highway could increase a manufacturer's competitiveness by reducing transport

costs. In this example, manufacturers who truck their output to customers spend less time on the road because of the new more direct route, and experience less wear and tear on their fleet of trucks. This allows the same amount of output to be delivered at lower cost. Also, the fleet of trucks will experience less down time for repairs because of the better-maintained newer road. Accordingly, public capital has been substituted for private capital, and the private capital stock becomes more efficient as a result. Alternatively, municipal investment in infrastructure may attract new industrial growth, fostering a complementary relationship between the two types of capital. Indeed, several papers have argued that public infrastructure competition has been important in regional competition for economic development (Bucovetsky 2005; Wakasugi 2005; and Justman et al. 2005).

Political leaders at various levels of government have recognized the importance of public infrastructure. In 2007 the Harper government dedicated $33 billion (to be spent over seven years) to infrastructure improvements. Likewise, on February 15, 2008, in a speech to the Federation of Canadian Municipalities, Liberal leader Stéphane Dion said, "We need to guard against the possibility that our children will inherit a crippling infrastructure deficit that includes crumbling bridges, leaking water pipes and insufficient public transit." Dion said that a Liberal government would allocate the first $3 billion of any surplus to debt service and the rest to infrastructure. Dion's message was well received by municipalities. The federation had previously indicated in a report released on November 20, 2007, that an investment of $123 billion was required to prevent a collapse of Canadian infrastructure. In March 2008, the Ontario government introduced legislation to allocate part of any surplus to infrastructure projects rather than to debt reduction, as required by a previous statute.

The next section explains what the infrastructure capital stock consists of, and attempts to assess the need for further investment in this area. Then, after a review of recent studies, I present empirical evidence on the impact of public infrastructure on the costs of production, labour productivity and composition of inputs in the Canadian manufacturing sector. The final section concludes the analysis and offers some policy recommendations.

The Need for Infrastructure Investment

Public infrastructure capital literally ranges from roads to rinks (Roy 2007). A large portion of public infrastructure capital is meant to be used in the productive process (such as roads, bridges, ports, water supply systems and waste management). Another portion is, by design, in the form of consumer goods meant to increase the quality of life in the community (such as recreational and cultural facilities, hospitals and health systems, educational facilities and sewage systems). The argument in favour of public funding and provision of infrastructure investment is based on the notion that the benefits to society as a whole are much larger than the benefits to individuals. Much infrastructure investment is either nonrival (meaning that its use by one individual does not prevent simultaneous use by others), nonexcludable (meaning it is difficult to prevent usage by individuals who have not paid for it) or both. For example, city streets are nonexclusive: once they have been constructed, it is virtually impossible to control access. As a result, private markets will undersupply this investment (or perhaps not supply it at all), even though the total social benefits outweigh the costs. In these cases, the government typically finances the investment, essentially "forcing" everyone to pay for it via taxes.[1] By the same line of reasoning, an individual has little incentive to fix potholes. Thus infrastructure maintenance is also typically funded by government.

This paper concentrates on the impact that current public capital has on the productive process and does not entertain the question of whether private provision of some or all of this capital would be more or less effective.

Investment in public infrastructure may take the form of new projects or it may be in the nature of maintenance or repair of existing capital structures. Both may have a significant effect on the productive capacity of a region. New roads, sewers, schools and other facilities are needed to attract new residential construction and new investment in physical plant and equipment by private manufacturing companies. However, without constant repair and maintenance, the existing stock of public capital will be eroded and become less efficient for production. Bridges may collapse, water mains may rupture and roads may become full of potholes to the extent that traffic is significantly slowed. Of course, the total capacity of such infrastructure is important, because,

even if it is in good condition, it may not be sufficient to satisfy the needs of consumers and businesses. Without adequate infrastructure, the net result may be a less attractive environment for private production, which can lead to increased business costs and reduced productivity, and in the end may cause a relocation of industrial and commercial facilities. In this way, infrastructure investment is essentially the same as any other investment in productive capital.

What is the current need for new infrastructure investment and maintenance? With respect to needed repairs, a report from the Federation of Canadian Municipalities (2007) entitled "Danger Ahead: The Coming Collapse of Canada's Municipal Infrastructure" estimates that 79 percent of the service life of Canadian roads, sewage systems and other key infrastructure components had passed by the date of the report. Gagnon, Gaudreault and Overton (2008) estimate that bridges have passed 57 percent of their useful life, that roads have passed 53 percent of their useful life and that water treatment plants have passed 63 percent of their expected life. They note that, until 2000, the average age of most infrastructure facilities had been increasing. Then contaminated drinking water hit the residents of Walkerton, Ontario,[2] and an overpass collapsed in Laval, Quebec.[3] These tragedies brought infrastructure problems to the front pages, and some degree of corrective action is now being undertaken. Further, a report by the Residential and Civil Construction Alliance, entitled "Ontario's Bridges: Bridging the Gap" (November 2007), argues that Ontario's bridges might not be safe and recommends that the provincial government assume control of all municipal bridges to ensure regular inspections and maintenance.

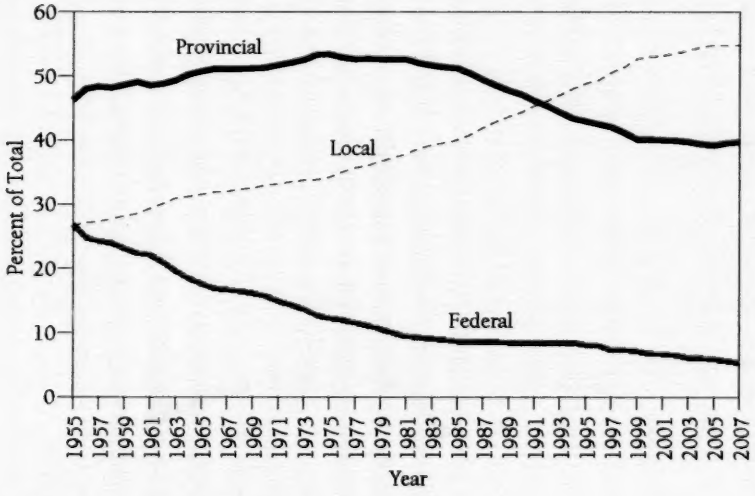
Increasingly in Canada the jurisdictional responsibility for funding much of public infrastructure has been shifted to the local or municipal level. Figure 1 shows the changes in the percentage of funding responsibility for infrastructure capital by level of government from 1955 to 2007. During this period the federal share of public infrastructure has steadily declined, from 26.9 percent in 1955 to only 5.3 percent in 2007, while that of the municipal or local level of government has increased from 26.7 percent in 1955 to 54.9 percent in 2007. The provincial share has been more or less constant, but it fell below the municipal share in 1992 and was at 39.8 percent in 2007. A strong argument can be made that it is efficient to have some public infra-

structure facilities (such as sewers and water supply) under the jurisdiction of local authorities, so that the local people can decide what sort of public infrastructure is really desired. However, local revenue sources have not kept pace with expenditure requirements, and the result has been a tendency to allow existing local infrastructure to deteriorate.

The fact that local revenues have not kept pace with the need for spending at the local level, particularly on infrastructure, has been recognized before. This "municipal fiscal deficit" cannot be stressed enough:

> *We conclude that the municipal fiscal deficit is real. Several key areas of municipal responsibility have expenditures which are rising considerably faster than municipal revenues. Deficits on the current account cause the municipality to reduce current expenditures on local services by the amount of the debt service charges. Deficits on the capital account may be justified as a way of having the cost of capital projects shifted to the future when the benefits of the projects will occur.*

Figure 1
Infrastructure Capital by Jurisdiction, 1955-2007



Source: Statistics Canada, CANSIM matrix 031-0002.

> *If municipalities are to achieve their goal of becoming efficient providers of local public services, they require an additional source of stable revenue. Otherwise, optimal planning and proper municipal budgeting will not be possible. (Brox and Brox 2007)*

Courchene (2007) notes that Canada's cities rely on property taxes (which, unlike sales and income taxes, do not grow with the economy or population) for 92.7 percent of their revenues, compared with American cities, which raise 72.8 percent of their revenues from this source. Indeed, European cities outside the United Kingdom generally raise less than half of their funds from property-based taxes. Unlike sales and incomes taxes, property taxes tend to increase much more slowly than either the growth of the economy in general or the specific expenditure required by local governments.

Courchene points out that the federal and provincial governments have been aware of this problem. The Martin government recognized and attempted partially to address the problem with a commitment to share revenue from the federal gas tax, in addition to exempting cities from parts of the Goods and Services Tax (GST) and providing increased funding for infrastructure projects under what was called the "New Deal for Canada's Communities," contained in the budget of 2005. Courchene further argues that the Harper government's reduction in the GST rate from 7 percent to 6 percent (and subsequently to 5 percent) provides an opportunity for provinces to increase their provincial sales tax rates and to pass the revenue on to their cities.

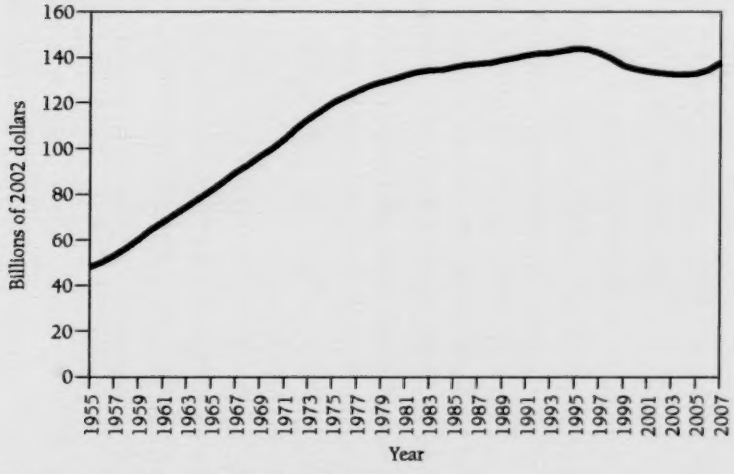
In this paper I analyze the impact of a specific component of public capital that represents investment in infrastructure facilities aimed mainly at aiding the productive process. I exclude all investments in the health and education sectors, even though many of these investments are made by the public sector. I also exclude all investment in buildings and in machinery and equipment, including investments in information and communications technology equipment that may well be important in promoting private sector efficiency. The effects of these types of "public capital" investments have been studied elsewhere (Brox 2007a, 2007b; 2008).

For the purposes of the analysis, public infrastructure capital is defined as the total stock of government-owned engineering capital net of straight-line depreciation, in constant dollars.[4] Public engineering capital consists of (1) highways, roads and bridges, which account for

just under 60 percent of the total; (2) other transportation facilities, including airports, railways, docks and canals, which account for approximately 6 percent of the total; (3) water supply systems, which account for about 15 percent of the total; (4) environmental projects, including waste and sewage disposal (treatment) systems, which represent about 10 percent of the total; and (5) others, including cultural, communications and outdoor recreational facilities, which make up the remaining 9 percent of the total.[5] As shown in figure 2, the constant-dollar stock of infrastructure showed a roughly consistent upward trend until approximately 1980, after which it continued to grow at a slightly slower rate until 1996. But beginning in 1996, the net stock of infrastructure actually declined, in part due to deficit-cutting measures at both the federal and provincial levels. Nonetheless, there has been a slight uptick in recent years.

How much infrastructure is required to maximize economic growth and development? This is not an easy question to answer. One approach is to examine trends over time of various infrastructure indi-

Figure 2
Stock of Public Infrastructure Capital, 1955-2007

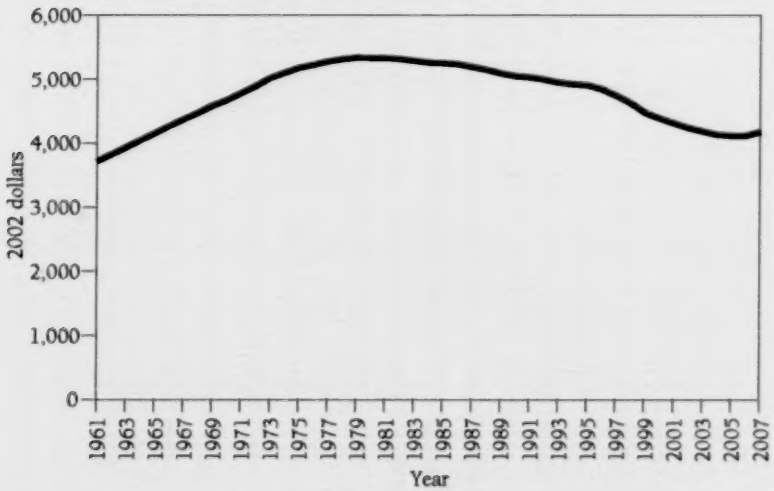


Source: Statistics Canada, CANSIM matrix 031-0002.

cators to determine whether the current infrastructure stock is low or high relative to previous periods. If we look at the constant-dollar stock of public infrastructure per capita (shown in figure 3), we see that it continually increased until 1980, reaching a maximum of $5,340. From 1980 to 1995 it declined gradually to $4,900, and dropped further to $4,125 in 2007, in part as a result of the deficit-cutting measures mentioned above. Returning this indicator to 1980 levels would require an investment of $38.3 billion in additional infrastructure.

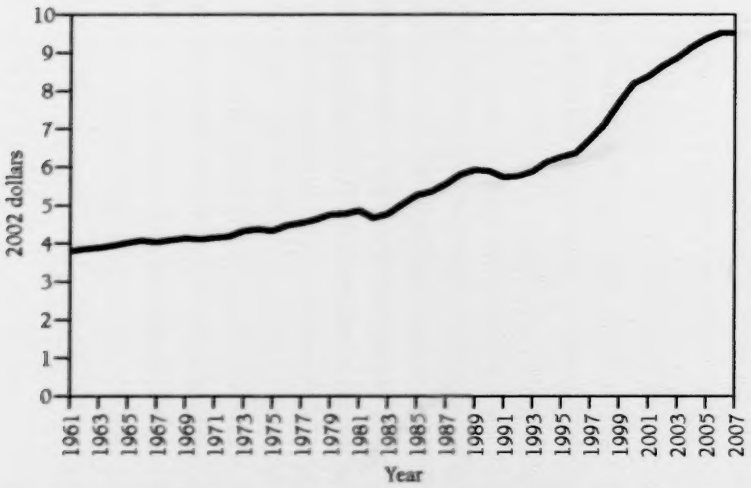
A second measure sometimes used to gauge infrastructure needs is infrastructure productivity, defined as the constant-dollar value of GDP divided by the constant-dollar value of infrastructure capital stock. This data is shown in figure 4. The constant-dollar ratio of GDP to infrastructure capital slowly increased from 3.8 in 1961 to 4.8 in 1981, then to 6.0 in 1990, 6.25 in 1996, and to 9.5 in 2007. One could argue that this increase in the productivity of infrastructure is a positive development for the economy, to the extent that more efficient use of public infrastructure has allowed output

Figure 3
Public Infrastructure Per Capita, 1961-2007



Source: Statistics Canada, data on infrastructure capital from CANSIM matrix 031-0002; data on population from CANSIM series v1.

Figure 4
Infrastructure Productivity (GDP per unit of public infrastructure capital), 1961-2007



Source: Statistics Canada, data on infrastructure capital from CANSIM matrix 031-0002; data on GDP from CANSIM series v41707150.

to grow more rapidly. But increases in this ratio could have another more ominous explanation: lack of adequate investment in infrastructure may have forced the use of other, perhaps less efficient, factors of production. The truth probably lies between these two extreme interpretations. However, to return to the 1996 ratio of 6.25 would require an increase in the stock of public infrastructure of $71.9 billion, or 52.3 percent of the current total.

While an examination of historical trends reveals peaks and valleys in infrastructure spending, these trends tell us nothing about what the "right" level of infrastructure is, nor do they take into account changes in the economy that may affect how much infrastructure is needed. One way to address this question directly is to calculate the implied rate of return on public capital and to compare this to the rate of return on private capital. Macdonald (2008) finds the return on public capital to be approximately 17 percent, compared with about 10 percent for private capital. Paul, Sahni and Biswal (2004) find a rate of return on public capital of 11 percent. Demetriades and Mamuneas

(2000) estimate the return on public capital for Canada to be about 20 percent, compared with a rate of return on private capital of 13 percent. My own empirical research suggests a rate of return on public capital of 20 to 25 percent, similar to or larger than those found by both Macdonald (2008) and Demetriades and Mamuneas (2000). Thus the consensus from the empirical literature is that the stock of public capital in Canada is too low, because the rate of return on public capital is greater than that on private capital.

Recent Government Infrastructure Initiatives

The federal government has recognized the need for increased investment in public infrastructure but, as previously mentioned, most of the current jurisdictional responsibility for funding such investments lies at the municipal level. The federal government has committed a significant amount of funding directly to such investments and even more in transfers "tied" to such investments. Over a seven-year period (2007-14), the federal government plans to allocate $33 billion to infrastructure projects.[6] Under its "Building Canada" plan, some $17.6 billion (over these seven years) will be available through the Gas Tax Fund and the GST rebate. This funding is to be "stable, predictable, and flexible," to allow "Canadian municipalities to plan for the longer term, using a dedicated source of funds to address their ongoing infrastructure needs" (Ministry of Finance, Canada, 2007).

Under the Building Canada Fund, a further $8.8 billion will be allocated to infrastructure owned by different levels of government or by the private sector. The fund gives priority to core infrastructure such as national highways, drinking water, public transit and green energy. It mentions environmental projects such as solid-waste management and brownfield redevelopment, and economic development undertakings such as short-line rail and short-sea shipping, connectivity and broadband, tourism and airports. Also included are resources for disaster mitigation, culture and sport. The funds are available to all levels of government and in "certain cases" to private industry (Ministry of Finance, Canada, 2007).

There are, of course, limits to the promised spending. All funds are to be cost-shared, with the federal share capped at 50 percent.

Municipal projects can expect only a one-third contribution, and privately owned projects face a one-quarter limit. It is also noted that projects that need more than $50 million from Ottawa will have to consider public-private partnerships. There is $1.25 billion for a "Public-Private Partnership Fund" (P3), and Ottawa will spend $25 million over five years to establish a federal P3 office.

The Quebec government also has recognized the so-called infrastructure gap. On October 11, 2007, it announced what it called "one of the largest economic projects in Quebec history." Quebec's infrastructure plan, "Foundations for Success," promised $30 billion of investments over five years. The plan was predicted to generate tens of thousands of jobs in every region of the province. On the announcement of the new infrastructure plan, Premier Jean Charest declared:

> *By investing massively, starting immediately, our government is showing vision, courage and determination to make up for decades of underinvestment in the upkeep of our collective infrastructures. Within 15 years, our hospitals will be among the most modern in the world, our roads will be in as good condition as those of our neighbours, our sewer and water systems will be able to support more development and our schools will become more welcoming environments, fostering academic achievement.*

On March 12, 2008, the Government of Ontario introduced legislation to dedicate a portion of any future surpluses to municipalities for infrastructure needs, such as improving roads and bridges, expanding transit and upgrading social housing.[7] Introducing the new legislation, Ontario Finance Minister Dwight Duncan said: "Investing in municipal infrastructure not only addresses the capital needs of our communities, but it also creates more jobs in the short term and prosperity in the long run." To the new policy direction, Doug Reycraft, president of the Association of Municipalities of Ontario, replied: "This is another significant step in the province's commitment to partnering with municipalities to help ease the infrastructure challenges they are facing" (Ontario Ministry of Finance 2008a).

Further, in the 2008 provincial budget released on March 26, 2008, the Ontario government committed $1 billion in new fund-

ing for municipal infrastructure in 2007-08, to be allocated as follows:

- $400 million for the Municipal Roads and Bridges Fund for communities outside Toronto
- $497 million for public transit in the Greater Toronto and Hamilton Area for Metrolinx projects and other transit priorities
- $100 million for infrastructure investments to rehabilitate existing social housing units, including energy-efficiency improvements. The government is also planning to make key public sector social housing providers eligible for Infrastructure Ontario's OSIFA loan program, which would provide up to $500 million in low-cost loans.

These investments will create an estimated 10,000 jobs during construction and will build on recent initiatives, including the $450 million Municipal Infrastructure Investment Initiative (MIII), a program that enabled municipalities to apply for funding for their own highest-priority projects (Ontario Ministry of Finance 2008b).

Do these recent budgetary measures imply that the infrastructure gap is a thing of the past? Not necessarily. Above I identified a possible infrastructure gap of up to $72 billion in new capital requirements, plus up to $123 billion in needed repairs to existing public infrastructure capital stock. The federal government's announcement of $33 billion is over a seven-year period, or less than $5 billion per year. The Government of Quebec announced $30 billion over five years, but with reference to a 15-year plan to address some of the needs. Ontario's recent commitment was much more modest, at $1 billion (with possible additional sums available if the year-end budget results in a surplus), but this comes on top of its ambitious ReNew Ontario plan, which will inject $30 billion into infrastructure over the next several years.

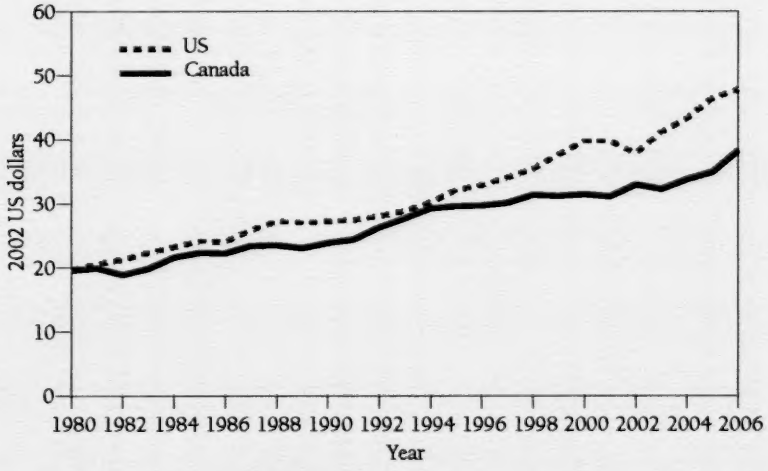
These measures are clearly welcome. They have drawn favourable comments from private and municipal partners, but they represent only a first step toward what is really needed. The infrastructure gap persists. The next question is, will this investment in public infrastructure provide a positive impact on labour productivity and the cost structure of the private manufacturing sector? Let us now turn to this question.

Historical Trends in Infrastructure Investment and Manufacturing Productivity

Canada, like the United States, experienced a productivity slowdown beginning in the 1970s that coincided with reduced growth in public investment. From 1973 to 1979, the ratio of public investment to GDP in Canada declined from 3.9 percent to 2.9 percent, and annual growth in manufacturing productivity growth decelerated from 2.2 percent to 0.6 percent. Trends in the United States were qualitatively similar.

Since the early 1980s a sizable manufacturing productivity gap had opened up between the United States and Canada (figure 5). In the early 1990s the gap closed somewhat, but from 1994 on growth in Canada trailed that of the United States considerably. Perhaps not coin-

Figure 5
Manufacturing Output per Hour Worked in Canada and United States, 1980-2006



Sources: United States — manufacturing output: Bureau of Economic Analysis; manufacturing hours: Bureau of Labor Statistics, based on establishment survey. Canada — manufacturing output: Statistics Canada, CANSIM II, series v328622 and v2034927; manufacturing hours: CANSIM II, series v2641562.
Note: "Output per hour" is the commonly used measure of total labour productivity. For ease of comparison, the Canadian figures have been converted to 2002 US dollars using the purchasing parity exchange rate.

cidentally, the stock of U.S. infrastructure capital has grown 24 percent since then, compared with a 3.5 percent decline in Canada.

This paper's analysis focuses on the manufacturing sector, despite the fact that it is nominally a small and diminishing share of the Canadian economy (or of any other industrial economy, for that matter), however measured. In 2007, manufacturing represented slightly more than 12 percent of the Canadian economy, measured as a share of either output or employment. By comparison, the manufacturing sector was 17 percent of output and 19 percent of employment in 1980 and 17.4 percent of output and 15.2 percent of employment in 2000.

Despite its diminishing relative size, the manufacturing sector is an extremely important part of the economy, particularly in Ontario and Quebec. Canadian exports are concentrated in manufacturing. Thus the pressures resulting from the high value of the Canadian dollar are falling disproportionately on manufacturers. As well, activity in service sector industries, especially warehousing, transport, wholesaling and to some extent financial services, tends to be driven by activity in the manufacturing sector. Furthermore, domestic demand for primary industries (mining, forestry and oil and gas) derives disproportionately from manufacturing activity, which is much more resource-intensive than other sectors of the economy. Thus, from a policy point of view, focusing on the linkages between infrastructure investment and manufacturing production is quite timely.

Empirical Studies of the Infrastructure-Productivity Relationship

It was noted earlier that there appears to be a correlation between infrastructure investment and manufacturing productivity, but it would be premature to infer that there is a causal relationship. Examination of this question requires rigorous empirical testing of a theoretical model of production with observed actual behaviour. Economists use two principal approaches to model the effects of infrastructure on the private production process. One approach models output as a function of purchased inputs (such as capital, labour, energy and materials) and incorporates infrastructure capital as a nonpurchased input. A second, related approach is to model business costs based on the prices of pur-

chased inputs, and then measure the extent to which the presence of infrastructure capital changes those costs. It is often argued that the cost function is preferable when studying the impact of elements such as public infrastructure, because it is easier to separate price (substitution) and output (quantity or scale) effects using this approach. Although the functional form may be of secondary interest to most readers, I do include some detail to the extent it is important for understanding the empirical results.

Among the earliest models used to study production was the Cobb-Douglas (1928) production function. This model imposed many of the assumptions of microeconomic theory. Economists interested in policy issues found this functional form too restrictive for many purposes, as interesting issues were imposed by assumption. Extensions to the theory of production led to so-called flexible functional forms that allowed these assumptions to be tested rather than imposed. In general, the most flexible functional forms include most of the more restrictive functional forms, like the Cobb-Douglas, as special cases. Thus, while the more restrictive models are considered to be useful teaching tools, the flexible functional forms are preferable for policy analysis.

While most research on the infrastructure-productivity link follows this flexible functional form empirical approach, early empirical works by Aschauer (1989a) and Munnell (1990) expand the Cobb-Douglas production function to include public capital stock and find that the public capital stock has an unusually large effect on private sector output. However, Tatom (1991, 1993) criticizes this methodology and strongly questions the infrastructure-productivity hypothesis. Others have pointed out that the early estimates are not credible due to their extraordinarily large size (Berndt and Hansson 1992). Aschauer's regressions find estimates of production elasticity of public capital to be between 0.38 and 0.56, and when these values are used to compute rate of returns, the conclusion is that one unit of government capital pays for itself in terms of higher output in a year or less. This is a rather improbable scenario.

Using production models that examine the growth rate rather than the level of infrastructure, Evans and Karras (1994) and Tatom (1991) find a negative (though statistically insignificant) effect for pub-

lic infrastructure. This is equally improbable. It is hard to believe that investment in highways, sewers, etc. would *decrease* business output. If infrastructure were in fact an obstacle to production, private producers would simply avoid using it, in which case it would have no effect at all.

As noted earlier, the production function framework has some limitations, because it omits input prices (which affect factor utilization and so bias the estimated coefficients). For this reason, much of the subsequent research on infrastructure's role in production has used the cost-function approach that incorporates public infrastructure as a "free" external input (Berndt and Hansson 1992; Lynde and Richmond 1992; Shah 1992; Conrad and Seitz 1994; Nadiri and Mamuneas 1994).

The results vary from study to study depending upon the exact sources of data used, the time period studied and the estimation model and methods used. Table 1 presents the results from some of the more recent studies. The majority indicate that infrastructure capital has a significant negative impact on the cost of production in the private sector. That is, as the private sector has more public infrastructure capital to work with, output is produced at a lower private cost, thus resulting in an improvement in productivity. The elasticities reported in table 1 show the percentage decrease in costs (or the percentage increase in output) that would result from a 1 percent increase in the stock of infrastructure.

Moreover, the majority of these studies also indicates that public and private capital are substitutes. This implies that most studies find that firms use less private capital in production when more public capital is available. Correspondingly, most studies find that public infrastructure makes private production more labour-intensive.

Wang (2005) studies the effect of Canadian government expenditure on private investment. He finds both a complementary and substitutability relationship, depending on the category of government expenditure. Specifically, infrastructure investment is found to have a substitute relationship with private investment in the next period. Government spending on health care, education, transportation, housing, security and debt service is found to have a complementary relation to private investment. The nature of the model used does not allow for the estimation of the effects on private costs of production nor on the total output impacts.

Table 1
Summary of Empirical Studies of Infrastructure-Productivity Link

Study	Cost (output) elasticity with respect to infrastructure	Sector studied	Relationship between infrastructure and private capital
Production function approach			
Aschauer (1989)	0.38 and 0.56	US manufacturing	Complement
Demetriades and Mamuneas (2000)	0.358 to 1.969 for 12 OECD countries 0.916 for Canada	OECD countries	Complement in short run, substitute in long run
Evans and Karras (1994)	Not significantly different from zero	Private nonfarm sector for a panel of US states	Substitute
Duggal, Saltzman and Klein (2007)	0.59	US IT sector	Complement
Tatom (1991)	Not significantly different from zero	US business sector	Substitute
Cost function approach			
Bernstein and Mamuneas (2008)	-0.16	processing industry	Canadian food Complement
Brox (2006)	-0.677	Canadian automotive industry	Substitute
Brox and Fader (2005)	-0.476	Canadian manufacturing sector	Substitute
Brox and Fader (1996)	-0.481 to -0.115	Atlantic Canada manufacturing sector	Substitute
Ezcurra et al. (2005)	-0.154	Spanish regions	Complement
Harchaoui, Tarkhani and Warren (2004)	-0.17 on average, significant variation	All Canadian industries	Complement
MacDonald (2008)	-0.22	Canadian manufacturing sector	Complement
Paul, Sahni, and Biswal (2004)	-0.40 to -0.10	Canadian manufacturing sector	Substitute (varies by industry)
Wang (2005)	n.a.	Private investment	Substitute

Source: Compiled by author.
n.a. = not available

Kalaitzidakis and Kalyvitis (2005) look at the impact of maintenance and repair expenditures on infrastructure, as opposed to the actual level of infrastructure capital stock on Canadian GDP, for the period 1956-98. While they do not calculate exact elasticities, their results suggest that the quality of capital goods, that is, the extent to which infrastructure is maintained, may be as important as the level of infrastructure in explaining private sector growth, particularly at the regional level.

Kalyvitis (2003) uses a growth model based on the Cobb-Douglas production function adjusted for the presence of human capital and infrastructure. The study finds that the growth rate of Canadian GDP is roughly proportional to the rate of infrastructure formation. Private capital also grows, albeit with a slight delay, suggesting that infrastructure and private investment are complements in the medium term.

Bernstein and Mamuneas (2008) study production in the Canadian food-processing industry. Their analysis indicate that a 1 percent increase in infrastructure formation results in a reduction of production costs in the food-processing industry by 0.16 percent. The cost reduction is the result of a reordering of the means of production; specifically, an increase in infrastructure formation causes the food-processing industry to use more private capital and less labour and fewer materials than it would otherwise.

Harchaoui, Tarkhani and Warren (2004) report the results of an earlier study by Statistics Canada employing a 1,400-observation panel data set to study 37 Canadian industries over a 40-year period. The model used is a translog cost function[8] and output demand function. They find that infrastructure effects vary widely across industries, with the largest effects being found for construction, transportation, and wholesale and retail trade. Among the manufacturing sectors, automotive equipment is found to have the largest response to changes in the level of infrastructure provided.

Duggal, Saltzman and Klein (2007) use a nonlinear production function to evaluate the effect of government infrastructure and private information technology (IT) capital on output growth. Their results show that both IT capital and public infrastructure made significant contributions to the technological surge in the 1990s.

Ezcurra et al. (2005) use a translog model and a panel data set to estimate regional cost functions for Spain. They study the impact on the

agricultural, industrial and service sectors of the Spanish economy. Both total public capital and transportation infrastructure are considered. A special part of their analysis is the consideration of regional spillover effects that may result from transportation infrastructure affecting the accessibility of a region, as well as of benefits occurring in a region other than the funding jurisdiction. They find that public infrastructure has a strong association with reduced costs, with an average elasticity –0.154. Private capital is found to be a substitute for public infrastructure and the spillover impacts are significant.

Justman, Thisse and van Ypersele (2005) offer a game-theory analysis of the use of infrastructure as a competitive regional policy. They argue that the use of regionally differentiated infrastructure may be more cost effective than subsidies at attracting firms to locate in their jurisdiction. Their conclusion is that some degree of coordination at a higher level of government may be needed in order to ensure regional diversity in infrastructure and reap the economic benefits of infrastructure "specialization." This would argue for a federal or provincial role in infrastructure projects that are currently being managed by municipalities.[9]

Other studies of the regional aspects of infrastructure investment have been carried out for the United States (Morrison and Schwartz 1996), for Canada (Brox and Fader 1996), for Germany (Seitz and Licht 1995), for Sweden (Berndt and Hansson 1992) and for China (Wakasugi 2005). These regional studies find that the size of the region has a positive significant effect on the magnitude of the infrastructure impact on productivity. Also, small well-connected regions often are affected as much by infrastructure spending in neighbouring regions as they are by investments within their borders. Finally, the regional studies show that competitive provision of infrastructure facilities has been successful in attracting private sector businesses.

Demetriades and Mamuneas (2000) estimate a flexible functional form variable profit function, with dynamic adjustments, for 12 OECD countries. The model allows for evaluation of the effect of public infrastructure both through time (short-run, intermediate-run and long-run effects) as well as across countries with different initial endowments of infrastructure. They find that for all 12 countries, public capital has positive long-run effects on output. The high rates of return in the long run indicate a significant underinvestment gap in public infrastructure in most of these

countries. They find the output elasticity of public infrastructure to vary from a low of 0.358 for the United Kingdom to a high of 1.969 for Norway. The value found for Canada is 0.910. The estimate for Canada is almost twice as large as Aschauer and Munnell's estimates for the United States, but this is due to the fact that the effect is measured over a longer period and hence includes the effects of changes in employment and private investment as well. By comparing the rates of return to public and private capital, they are able to determine whether the level of public infrastructure is optimal. They find that "there remain significant under-investment gaps in public capital in the United Kingdom, France and Canada" (2000, 710).

Paul, Sahni and Biswal (2004) study 12 Canadian manufacturing industries for the period 1961 to 1995 and find that infrastructure investment significantly reduces the cost of production in nine of the 12 industries, with the other three (chemical and chemical products, electrical and electronic products, leather and allied products) having an impact not significantly different from zero. They also find that public infrastructure capital is a substitute for both private capital and labour in most industries.

Macdonald (2008) employs several functional forms for both production and cost, using panels of provincial accounts data and the Statistics Canada KLEMS[10] database to study the effects of infrastructure on private production. Macdonald's estimated rate of return for public infrastructure from the production function model is 35 percent, while his estimated rate of return for public infrastructure from the cost function model is 17 percent. He concludes that the cost function estimates are more reasonable, but also notes that they are higher than the rate of return to private capital calculated by a number of methods.

Brox and Fader (1997 and 2002) look at production in the electronics and auto parts manufacturing sectors in Canada and find that firms using just-in-time production processes have a cost advantage over other firms. Given the strong supply-chain linkages between Canada and the United States, this brings into focus the critical importance of improved public infrastructure in the areas of security and border crossings.

To sum up, most of the published studies find that increases in the stock of infrastructure are strongly associated with reducing manufacturing costs, and hence improving manufacturers' competitive posture. These cost reductions are substantial, with transportation, construction, trade and automotive manufacturing reaping the largest savings.

Refining Theoretical and Empirical Links between Public Infrastructure and Private Costs

Most of my own published research on the innovation-productivity relationship takes a flexible, functional form, empirical approach.[11] I employ a variable-cost version of the constant elasticity of substitution translog (CES-TL) model, which is commonly employed by economists to study production processes (Pollack, Sickles and Wales 1984). This model explains the optimal input mix that will result in the lowest cost of production for a given level of output. As mentioned before, the cost-function approach has advantages over the production-function approach, as it allows for better separation of the effects of changes in levels of output, changes in input prices and changes in other factors beyond the direct control of the firms (in the current context, technology and infrastructure) when making their production decisions. The CES-TL model also has certain advantages over simpler cost-function models in that it imposes fewer theoretical restrictions and contains most of the more restrictive functional forms as special cases. Therefore, this version of the model allows nested testing of alternative functional forms to determine which version most closely corresponds to actual firm behaviour. The exact functional form used here and its mathematical derivation are explained in the technical appendix.

To implement the model empirically, I specify four private factor inputs: (1) labour, (2) capital, (3) energy and (4) intermediate inputs (materials). If production decisions are in fact affected by infrastructure, then the traditional production function must be extended to allow for these effects. Therefore, I include the level of the infrastructure capital stock as an exogenous (fixed) factor that affects the cost relationship. It is beyond the control of the private firms, but they will react to changes by altering the mix of private inputs used in production.

An initial question that needs to be answered is whether public infrastructure investment has any impact on the production decisions of Canadian manufacturers. To do so, the model is fitted to data under the assumption that such effects do not exist (i.e., the factor bias effects, discussed in the appendix, are forced to be zero) and compared with the unrestricted model to determine the likelihood of this hypothesis. Using a likelihood ratio test, the hypothesis is rejected with more than 99 per-

cent certainty (see appendix table A1 on page 43 for the test statistics and *P*-values).

Another important modelling question is whether the chosen functional form accurately represents business decisions regarding production. As is evident in the earlier discussion of the existing literature on infrastructure, most empirical studies use the Cobb-Douglas or translog functions because of their mathematical simplicity. By employing a more general functional form (constant elasticity of substitution-translog, or CES-TL) that can be constrained to replicate simpler models, I am able to test the contention that simpler models suffice for the analysis of manufacturing production.

If the parameter σ (which measures how easy it is to substitute one input for another; see the technical appendix) were equal to 1, then the CES-TL model would be identical to the translog model. But the actual unrestricted estimate of σ is in fact negative, strongly rejecting this notion. A formal statistical test similar to the likelihood ratio described above shows conclusively that the more complex CES-TL functional form is superior to simpler models. This suggests that the interplay between infrastructure and other factors of production is more complex than would be implied by more restrictive models. For example, if a new highway is built, firms may build new factories or reduce their transport costs by more efficient shipping from existing plants. This implies that policy-makers must be very careful about what kinds of infrastructure investments are undertaken.

Cost elasticity measures are reported in table 2. The cost elasticity with respect to output shows the percentage change in production costs for each 1 percent increase in output. Thus, a value less than one means that costs will increase less rapidly than production (implying a reduction in average costs), indicating increasing returns to scale. Put more simply, there are too many manufacturing plants in Canada, each producing too little output.

The output cost elasticity for total Canadian manufacturing is 0.903, which indicates modest increasing returns to scale. Automotive manufacturers, with a cost elasticity of 0.802, could reduce average costs to an even greater extent by increasing their scale. Not surprisingly, the corresponding elasticities are generally smaller (and hence the potential for increasing returns to scale much larger) in the Atlantic provinces, ranging from 0.345 in Prince Edward Island to 0.843 in New

Brunswick. Due in part to demographic and geographic realities, industry in Atlantic Canada operates on a scale that is smaller than that needed to minimize production costs.

A related indicator of overall cost trends is the rate of cost diminution, which shows how production costs change over time, abstracting from changes in the cost of purchased inputs. It can thus be considered a measure of trends in the overall efficiency of production. The coefficients are negative across the board, meaning that overall production efficiency has increased over time. For example, the value of –0.081 for automotive manufacturing means that costs declined by an average of about one tenth of a percent annually over the sample period. Slightly smaller efficiency gains are found for the entire Canadian manufacturing sector, but such effects are statistically insignificant in the Atlantic provinces.

The cost elasticity with respect to infrastructure shows the percent change in production costs associated with a 1 percent increase in the stock of infrastructure and thus directly measures the "productivity effect" of infrastructure investment. For example, the value of -0.677 for the auto sector implies that a 10 percent increase in infrastructure capital would decrease the cost of producing a given amount of output by 6.8 percent — or, put another way, increase productivity by about the same amount. The infrastructure effect found for all manufacturing is smaller (-0.476), but nonetheless at the high end of estimates by other researchers. The influence of infrastructure on costs is smaller in most of Atlantic Canada, with elasticities ranging from -0.481 for Newfoundland to -0.115 for New Brunswick. This may be due to the stock of infrastructure being relatively closer to the optimal level than for Canada as a whole, or it may be due to the scale effects mentioned above.

A final question of interest is how infrastructure investment affects the mix of inputs used in manufacturing production. The factor bias effects with respect to infrastructure provide answers, because they represent the change in input use resulting from a 1 percent increase in the stock of infrastructure. For example, γ_{lf}, the labour effect, is positive and γ_{kf}, the capital effect, is negative, for both total manufacturing and automotive manufacturing, meaning that increases in the infrastructure stock result in more hiring and less investment. This confirms the results of earlier research that found infrastructure and private investment to be substitutes, but also sug-

Table 2
Manufacturing Cost Elasticities in Atlantic Canada and Canada as a Whole

	Atlantic Canadian Manufacturing					
	Newfoundland	Prince Edward Island	Nova Scotia	New Brunswick	Canadian manufacturing sector	Canadian auto sector
Cost elasticity with respect to output (ϵcy)	0.698** (4.543)	0.345* (2.242)	0.694** (4.816)	0.843** (8.524)	0.903** (18.952)	0.802** (7.406)
Cost elasticity with respect to infrastructure (ϵcf)	-0.481* (-3.584)	-0.156* (-1.973)	-0.237* (-2.721)	-0.115* (-2.004)	-0.4761* (-3.6156)	-0.677* (-1.744)
Rate of cost diminution (ϵct)	-0.083 (-0.890)	-0.042 (-0.650)	-0.035 (-0.566)	-0.015 (-0.238)	-0.052* (-5.667)	-0.081** (-8.682)
Factor bias effects with respect to infrastructure						
Labour (γlf)	0.079** (4.989)	0.000 (0.023)	-0.029** (-4.334)	-0.000 (-0.044)	0.0647** (4.4321)	0.094* (3.256)
Capital (γkf)	-0.014 (-0.565)	-0.046* (-3.211)	-0.000 (-0.044)	-0.043* (-2.242)	-0.0600* (-2.114)	-0.021* (-2.871)
Energy (γef)	0.017* (2.301)	0.015* (3.676)	0.021** (5.593)	0.026** (6.108)	0.0118** (5.6979)	0.004* (2.060)
Materials (γmf)	-0.082* (-2.466)	0.031* (2.104)	0.008* (3.042)	0.047** (6.246)	0.0165* (2.3128)	0.015 (1.636)

Sources: Adapted by the author based on Brox (2006), Brox and Fader (2005), and Brox and Fader (1996).
Note: The derivation and further interpretation of all of these elasticities are provided in the technical appendix.
Notation: l = labour, k = capital, e = energy, m = materials, f = infrastructure, c = cost, t = time
T-statistics are in parentheses.
*$p < 0.05$ **$p < 0.1$

gests that an ancillary effect of infrastructure spending is a modest increase in private employment over and above the direct employment of the infrastructure investment itself.

Summary and Policy Conclusions

The main message of the foregoing analysis is that there is a significant need for more public infrastructure investment in Canada. New facilities are required to allow for growth of existing industries, to attract new industries and private investment and to enhance Canada's international economic competitiveness. In addition, in all regions of Canada, infrastructure is aging, and investments in repair and maintenance are necessary to shore up the quality of the current stock. The estimated dollar value of the required investment is on the order of $200 billion — up to $72 billion in new infrastructure facilities, depending on how the gap is measured, and up to $123 billion in repairs and upgrades to existing facilities. Recent announcements by Ottawa and the Quebec and Ontario governments have committed up to $65 billion over the next five to ten years to address the infrastructure gap, but it is clear that this financial commitment will need to be sustained (and even increased) over an even longer period of time to close the infrastructure gap fully.

Why is the current response of government inadequate? At least part of this question is answered by the fact that much of the responsibility for infrastructure has been shifted to the local level of government, whose revenue sources are limited and cannot keep up with needs. This municipal fiscal shortfall has been recognized, but not fully remedied.

A well-maintained infrastructure is of primary importance to public safety (as the collapse of the Boulevard de la Concorde overpass and the contamination of the water supply in Walkerton tragically illustrate), but it serves an equally important economic development purpose. It is universally agreed that infrastructure plays a critical role as a basic foundation for industrial development (which is almost the definition of "infrastructure"), but the large body of research surveyed here shows conclusively that changes in the stock of infrastructure have important ongoing effects on the cost structure, choice of inputs and productive

capacity of individual firms. My analysis of the Canadian manufacturing sector over the past three decades suggests that a sustained 10 percent annual increase in infrastructure spending (which is approximately the amount promised in recent federal and provincial infrastructure initiatives) could reduce manufacturing unit production costs by nearly 5 percent per year — a welcome development in the context of the strong Canadian dollar. This is equivalent to a 5 percent increase in productivity, which would help narrow the Canada-US manufacturing productivity gap and enhance the sector's competitive profile.

The analysis also shows that infrastructure investment has important interactions with investment and employment decisions of Canadian manufacturers. Although some studies suggest that infrastructure and private investment are complementary, my empirical work for Canada shows them to be substitutes, meaning that additional infrastructure investment allows companies to allocate resources to other inputs in the short term. Over a longer time frame, however, the productivity of private capital is enhanced by infrastructure investment. This increases its rate of return, which increases the number of profitable investment projects. When making decisions regarding large infrastructure projects, policy-makers must consider their interactions with other policies that affect the cost of private capital, such as corporate tax rates and sales taxes on investment goods.

A second observation that is not immediately intuitive is that infrastructure investment encourages manufacturing firms to use labour inputs more intensively, which translates into more jobs. A typical (but misplaced) fear of productivity growth is the notion that it increases unemployment. But based on my empirical analysis of the infrastructure-labour input relationship, the increases in infrastructure spending committed by the federal, Ontario and Quebec governments would not only enhance productivity, they could actually boost manufacturing employment by as much as 0.6 percent per year relative to baseline trends. While this is small when measured against recent job losses and would not come close to offsetting them, it represents movement in the right direction.

Public infrastructure has built this nation. We will not continue to be competitive if our viaducts are in danger of collapse and our water

systems in danger of contamination. If we do not start shoring up our infrastructure deficit now, the cost in the future may be more than we can bear either physically or financially. This is a national undertaking and cannot be left to any one jurisdiction. Canadian competitiveness and our status as a developed country depend on modern, efficient, and well-maintained public infrastructure.

Technical Appendix

This section presents the specification of the functional form of the model used in the analysis and the mathematical derivation of the specific model used.

Infrastructure is important for enhancing productivity and growth of the private sector by providing alternative productive facilities. If the private sector production function is altered in some way by the quantity and quality of infrastructure capital, then the usual production function must be altered to include these effects. We write the production function as

$$Y = f(X_i, EF) \qquad [A1]$$

where Y is the maximum output that can be produced in a time period, given quantities of the inputs x_1, x_2, ... x_n, and EF are the exogenous factors beyond the span of control of the producing unit. If equation [A1] is a well-behaved neo-classical production function, there exists a cost function dual to the production function, having the general form

$$C = g(Y, P_i, EF) \qquad [A2]$$

where C is the total private cost of producing output Y, given that the input quantities x_i have been purchased at prices P_i, and that costs are also conditional on exogenous factors EF.

To implement the model empirically, we specify four private factor inputs: (1) labour, (2) capital, (3) energy and (4) intermediate inputs (materials). As well, we identify two important exogenous factors that affect the cost relationship: (1) the state of technical knowledge and (2) the amount of infrastructure capital. Thus the cost function is specified as

$$C = g(Y, P_l, P_k, P_e, P_m, T, F) \qquad [A3]$$

where C is total cost; Y is output; P_l, P_k, P_e, P_m are the prices of labour, capital, energy and materials respectively; t is an index of time representing disembodied technical change; and F is the (exogenous) stock of infrastructure capital. We employ the CES-TL first specified

by Pollack, Sickles and Wales (1984) to estimate equation [A3] which can be specified as

$$
\begin{aligned}
&lnC = lnC\,(Y, P_l, P_k, P_e, P_m, T, F) \\
&= a_o + \alpha_y\, lnY + 0.5\,\alpha_{yy}\,(lnY)^2 + ln\,(\sum_{i=1}^{n}\alpha_i\, P_i^{(\beta-\omega)})^{1/(\beta-\omega)} \\
&+ 0.5\sum_{i=1}^{n}\sum_{j=1}^{n}\gamma_{ij}\, lnP_i\, lnP_j + \sum_{i=1}^{n}\gamma_{iy}\, lnY\, lnP_i \\
&+ \sum_{i=1}^{n}\gamma_{it}\, T\, lnP_i + 0.5\,\gamma_{tt}\,(T)^2 + \gamma_{yt}\, T\, lnY \\
&+ \sum_{i=1}^{n}\gamma_{if}\, lnF\, lnP_i + 0.5\,\gamma_{ff}\, ln\,(F)^2 + \gamma_{yf}\, lnF\, lnY \\
&+ \gamma_{tf}\, T\, lnF + \gamma_t\, T + \gamma_f\, lnF
\end{aligned}
\qquad [A4]
$$

where σ is the elasticity of substitution in the CES-framework, the a_o, α_i's, and γ_i's are parametric constants and all other variables are as defined above.

Using Shephard's lemma we obtain the cost shares of the variable inputs as

$$
\begin{aligned}
&S_i = \frac{lnC(Y, P_l, P_k, P_e, P_m, T, F)}{lnP_i} = \frac{X_i P_i}{C} \\
&= \gamma_{iy}\, lnY + [\,\alpha_i\, P_i^{(\beta-\omega)}]\,[\sum_{j=1}^{n}\alpha_j\, P_j^{(\beta-\omega)}]^{-1} + \sum_{j=1}^{n}\gamma_{ij}\, lnP_j \\
&+ \gamma_{it}\, T + \gamma_{if}\, lnF,\ i = 1,\ldots,n
\end{aligned}
\qquad [A5]
$$

The following restrictions imposed on equations [A4] and [A5] imply that the CES-TL cost function is well-behaved:

$$
\begin{aligned}
&\text{s.t.}: \gamma_{ij} = \gamma_{ji},\ i \neq j\,; \sum_{j=1}^{n}\gamma_{ij} = \sum_{i=1}^{n}\gamma_{ji} = 0\,; \\
&\sum_{i=1}^{n}\gamma_{iy} = 0\,; \sum_{i=1}^{n}\gamma_{it} = 0\,; \sum_{i=1}^{n}\gamma_{if} = 0\,;\ and \sum_{i=1}^{n}\alpha_i = 1.
\end{aligned}
\qquad [A6]
$$

These restrictions imply that the cost-minimizing demand functions are homogeneous of degree zero in prices ($\sum\gamma_{ij} = \sum\gamma_{ji} = 0$),

and that the Slutsky symmetry ($\gamma_{ij} = \gamma_{ji}$) and adding up conditions ($\sum\gamma_{iy} = \sum\gamma_{it} = \sum\gamma_{if} = 0$) are satisfied. As well, for estimation purposes, the normalization condition ($\sum\alpha_i = 1$) is also part of the maintained hypothesis.

This model is non-homothetic and provides certain advantages over the TL system and its variants. Among other things, the CES-TL belongs to the same family of so-called flexible forms. However, the CES-TL (1) combines the TL and the CES of the Arrow-Chenery-Minhas-Solow type increasing, thus the substitution possibility patterns as compared with substitution patterns implied either by the TL or the CES technologies; (2) includes, as special cases, both the TL production technology and the CES production technology; and (3) allows nested testing using the traditional statistical methods.

The parameter estimates from equations [A4] and [A5] are utilized to compute Allen-Uzawa partial elasticities of substitution, which are measures of the curvature of the production isoquant and suggest substitutability of inputs, if positive, or complementarity, if the value computed is negative.

The formula for the Allen-Uzawa elasticities of substitution is given by

$$\sigma_{ij} = \begin{cases} (\sigma - 1)\,[\alpha_i P_i^{\theta\omega}]\,[\sum_{i=1}^{n} \alpha_i P_i^{\theta\omega} - \alpha_i P_i^{\theta\omega}]\;[\sum_{i=1}^{n} \alpha_i P_i^{\theta\omega}]^{-2} S_i^{-2} \\ \quad + [\gamma_{ii} + S_i (S_i - 1)]\, S_i^{-2},\ i = j \\ (\sigma - 1)\,[\alpha_i P_i^{\theta\omega}]\,[\alpha_j P_j^{\theta\omega}]\,[\sum_{j=1}^{n} \alpha_j P_j^{\theta\omega}]^{-2} S_i^{-1} S_j^{-1} \\ \quad + (\gamma_{ij} + S_i S_j) S_i^{-1} S_j^{-1},\ i \neq j \end{cases} \qquad [A7]$$

and the price elasticities of input demands are

$$\epsilon_{ij} = \begin{cases} \sigma_{ii} S_i,\ i = j \\ \sigma_{ij} S_j,\ i \neq j \end{cases} \qquad [A8]$$

Global convexity of the cost function requires that all own-partial elasticities of substitution, σ_{ii}'s and, consequently, all own-price elasticities of input demand, ϵ_{ii}'s, be negative at all points. No a priori restrictions are imposed on the cross-partial elasticities.

Several other useful measures that characterize the cost structure under examination can be calculated. The total and average cost elasticities with respect to output are measured by equations [A9] and [A10] respectively:

$$\epsilon_{c\,y} = \frac{\partial lnC}{\partial lnY} = \alpha_y + \alpha_{yy}\, lnY + \sum_{i=1}^{n} \gamma_{iy}\, lnP_i + \gamma_{yt}\, T + \gamma_{yf}\, lnF \qquad [A9]$$

$$\epsilon_{c\,/\,y} = \frac{\partial ln\,(C\,/\,Y)}{\partial lnY} = \frac{\partial (lnC - lnY)}{\partial lnY} = \epsilon_{c\,y} - 1 \qquad [A10]$$

These elasticities can, among other things, be used to identify economies of scale. Long-run scale economies are the reduction of cost, as all inputs are changed, but with constant input prices. Measures of these economies of scale can be inferred from the elasticity of total cost, the elasticity of average cost and/or the dual returns-to-scale index.

Ohta (1974) defines the dual rate of returns to scale as

$$\epsilon_{c\,y}^{-1} = \frac{1}{\epsilon_{c\,y}} \qquad [A11]$$

and the dual of total factor productivity is the rate of cost diminution, computed as

$$\epsilon_{c\,t} = -\frac{\partial lnC}{\partial T} = -\left(\gamma_t + \sum_{i=1}^{n} \gamma_{it}\, lnP + \gamma_{tt}\, T + \gamma_{yt}\, lnY + \gamma_{tf}\, lnF\right) \qquad [A12]$$

The primal rate of total factor productivity is then defined by Ohta (in its dual form) to be

$$\epsilon_{tfp} = \epsilon_{c\,y}^{-1}\, \epsilon_{c\,t} \qquad [A13]$$

In addition to the above information on total factor productivity, an alternative view of productivity is factor specific. Average input productivities with respect to output are typically measured as Y/X_i. For example, output per hour or output per unit capital are usual average productivity measures. The average productivity elasticity that captures the elasticity of the ith factor-specific average productivity with respect to the jth input price is

$$\pi_{ij} = \frac{\partial ln(Y / X_i)}{\partial lnP_j} = -\epsilon_{ij} \quad i, j = K, L, E, M. \qquad [A14]$$

Other factor-specific average productivity elasticities are:

$$\pi_{iy} = \frac{\partial ln(Y / X_i)}{\partial lnY} = 1 - \epsilon_{cy} - \gamma_{yi} S_i^{-1} \qquad [A15]$$

and

$$\pi_{it} = \frac{\partial ln(Y / X_i)}{\partial lnT} = -\epsilon_{ct} - \frac{\gamma_{it}}{S_i} \qquad [A16]$$

We also obtain share elasticities by differentiating the logarithm of the cost function twice with respect to the logarithms of input prices:

$$\tau_{pi} = \frac{\partial^2 lnC}{\partial lnP_i^2} = \gamma_{ij} for\ i = j \qquad [A17]$$

These parameter estimates give the response of the cost shares of all inputs to proportional changes in the input prices.

Also, differentiating the logarithm of the cost function twice with respect to the logarithms of the input prices and the level of output yields measures of biases of scale:

$$\tau_{yp_i} = \frac{\partial^2 lnC}{\partial lnP_i\ \partial lnY} = \gamma_{iy} \qquad [A18]$$

If this scale bias is positive, the cost share of the factor input increases with a change in the level of output. If negative, the cost share decreases with a change in output; if the scale bias is zero, the cost share is independent of the change in output. An equivalent alternative interpretation is that if this scale bias is positive, the cost flexibility increases with the input price. If negative, the flexibility of cost decreases with an increase in input price, and if zero, the cost flexibility is independent of input price.

Differentiating the logarithm of the cost function twice with respect to the level of output yields yet another piece of information about cost flexibility:

$$\tau_{yy} = \frac{\partial^2 lnC}{\partial lnY^2} = \alpha_{yy} \qquad [A19]$$

If this parameter estimate is positive, negative or zero, the cost flexibility is increasing, decreasing or independent of the level of output.

Because the impact of academic research on private sector output is of primary importance to this research, we add the following elasticity calculations specific to the fixed factor component (infrastructure capital) which is computed in a way similar to the elasticities above:

$$\epsilon_{cf} = \frac{\partial lnC}{\partial lnF} = \gamma_f + \gamma_{yf} \ln Y + \sum_{i=1}^{n} \gamma_{fi} \ln P_i + \gamma_{ff} \ln F + \gamma_{tf} T \qquad [A20]$$

This elasticity is the saving in private production cost resulting from an increase in F. The impact of infrastructure capital on factor specific average productivities is measured by

$$\pi_{if} = \frac{\partial \ln (Y / X_i)}{\partial lnF} = - \epsilon_{cf} - \frac{\gamma_{if}}{S_i} \qquad [A21]$$

Finally, the estimated signs of the research/factor input interactive coefficients in the cost function will indicate whether infrastructure capital is a substitute of, or a complement to, individual factors of production.

The model is estimated for Canada using annual data for the total of manufacturing industries. Data for the total cost of manufacturing, separated into the cost of fuel and electricity, cost of materials and supplies, the cost of labour, the cost of capital and the value of output produced, comes from Statistics Canada (catalogue #31-203). The stock of public infrastructure series has been constructed using available data on mid-year net stock figures from Statistics Canada *Fixed Capital Flows and Stocks, National Wealth and Capital Stock Section*, Cansim matrix 31-002. The price of labour has been computed from the manufacturing series using information on the number employed and total salaries and wages paid. The price of materials has been proxied by the *Canadian Industrial Price Index*. The price of energy has been computed by calculating the total amount of energy consumed by the manufacturing industry (in peta-

joules) from *Consumption of Purchased Fuel and Electricity by Manufacturing 1962-1978* (catalogue #57-506) and combining that series with a series published in the *Quarterly Report on Energy Supply-Demand in Canada* (catalogue #57-003) that reports petajoule use from 1978 to 2001.

Finally, the price of capital has been computed using the following relationship:[12]

$$P_k = IP_k (1 + \theta + r) \qquad [A22]$$

where P_k is the price of capital services, θ is the depreciation rate, r is the market rate of interest and IP_k is the implicit price of capital for the manufacturing sector computed from *Fixed Capital Flows and Stocks* (catalogue #13-568). For estimation purposes, all prices have been normalized using base year 1986 equal to unity.

For CES-TL we assume additive error terms for cost and input-share equations. These error terms are postulated to have joint normal distributions with mean zero vector, [0,...,0], and a constant variance-covariance matrix W. The cost and share equations are jointly estimated by the method of Full Information Maximum Likelihood (FIML) contained in the *Shazam (Version 9.0, 2001)* econometric computer program. This technique

1) maximizes the likelihood function for the entire system by choice of all parameters, subject to all a priori restrictions;

2) gives consistent and asymptotically efficient estimators; and

3) is suitable for estimating systems of equations involving constrained coefficients of different structural equations and certain restrictions on the error structure.

However, since the sum of the input cost-share equations is unity, the variance-covariance matrix will be singular. To avoid this, one of the input cost-share equations must be deleted from the estimation procedure. Thus the FIML estimation procedure is applied to derive estimates of the parameters of the behavioural equations for the cost shares for labour, capital and energy and for the total cost equation. The estimates for the deleted equation (the cost share of intermediate inputs) are obtained by using the adding-up constraints.

Table A1
Tests of Restricted Versions of the Infrastructure-Augmented Manufacturing Production Model

Hypothesis	Sector	Log likelihood value	Test statistic	Critical value (99.5 percent confidence level)	Hypothesis rejected?
Unrestricted CES-TL model	Total Canadian manufacturing	614.62	N/A (point of comparison)	N/A	N/A
	Canadian automotive sector	540.25	N/A (point of comparison)	N/A	N/A
Public infrastructure has no effect on production decisions	Total Canadian manufacturing	557.42	114.00	21.96	Yes
	Canadian automotive sector	485.12	110.27	21.96	Yes
Translog function performs as well as CES-TL	Total Canadian manufacturing	578.69	72.00	7.88	Yes
	Canadian automotive sector	500.10	80.29	7.88	Yes

Source: Adapted from Brox (2006) and Brox and Fader (2005).

Notes

1 In the case of limited-access highways and bridges, the use of tolls becomes economical and practical, allowing the owners of the infrastructure to make sure that all users of the resource pay for it.

2 In May 2000, Walkerton's drinking water system became contaminated with deadly bacteria, primarily *Escherichia coli* O157:H7. Seven people died, and more than 2,300 became ill. (Report of the Walkerton Commission of Inquiry, prepared by Mr. Justice Dennis O'Connor) www.attorneygeneral.jus.gov.on.ca/english/about/pubs/walkerton/part1/

3 See "Commission of Inquiry into the Collapse of a Portion of the de la Concorde Overpass," Government of Quebec, www.ceve.qgov.qc.ca/Rapport/index.html

4 Constant dollars are used to capture an estimate of the quantity of the stock adjusted for the impact of inflation. The figures shown in figure 2 are in constant 2002 dollars. The data in the earlier published papers uses constant dollars measured in earlier years' prices.

5 The composition of infrastructure capital is based on data contained in Roy (2007), Harchaoui, Tarkhani and Warren (2004) and Gagnon, Gaudreault and Overton (2008). For a fuller discussion of alternative definitions and classifications of infrastructure investment, see Baldwin and Dixon (2008).

6 The totals reported are those combining the 2006, 2007 and 2008 budgets.

7 Previously, the statutory requirement was that all surpluses would be used to pay down the outstanding debt of the province.

8 The translog model is another example of the so-called flexible function form model.

9 The desirability of senior level co-ordination of projects could usefully be tied to the need for funding to supplement local revenue sources available for infrastructure projects.

10 KLEMS stands for capital, labour, energy, materials and services inputs.

11 The analysis presented here is based on research published in *Canadian Journal of Regional Science* (1996), *Applied Economics* (2005) and the *Journal of Economic Asymmetries* (2006).

12 See Field and Grobnstein (1980). Berndt and Hansson (1992) state (N158) that, in many cases, assuming the marginal corporate tax rate is zero may be realistic.

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This publication was produced under the direction of Jeremy Leonard, Research Director, IRPP. The manuscript was copy-edited by Anne Holloway, proofreading was by Wendy Thomas, production was by Chantal Létourneau, art direction was by Schumacher Design, and printing was by AGL Graphiques Inc.

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To cite this document:

Brox, James A. 2008. "Infrastructure Investment: The Foundation of Canadian Competitiveness." *IRPP Policy Matters* 9 (2).